Naval Submarine Medical Research Laboratory

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**Location and Triage of Disabled Submarine (DISSUB) Survivors:
Validating Equipment and Procedures**

by

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This report describes findings on an assortment of technologies focused on the location and triage of disabled submarine (DISSUB) survivors. In a DISSUB scenario, survivors are exposed to numerous threats such as hyper-/hypothermia, buildup of toxic gases, increased carbon dioxide levels, and/or decreased levels of oxygen.Three specific areas of technology were investigated in this initial assessment: biosensor monitoring, expedited location of casualties, and rapid life/death determination. Overall, 10 pieces of equipment were tested and only one was recommended for use in its current state. This was the Naval Firefighter Thermal Imager (NFTI) that is already in place onboard submarines. While several other technologies demonstrated great potential for future benefit, in their current state they were either prohibitively costly or their function was performed better using simpler and more reliable techniques such as confirming a palpable carotid pulse.

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ABSTRACT

This report describes findings on an assortment of technologies focused on the location and triage of disabled submarine (DISSUB) survivors. In a DISSUB scenario, survivors are exposed to numerous threats such as hyper-/hypothermia, buildup of toxic gases, increased carbon dioxide levels, and/or decreased levels of oxygen. These could easily render any survivors unresponsive and hinder efficient, focused triage and rescue efforts. Further confounding rescue efforts, first responders may have varying levels of medical experience and are seeking to locate and triage casualties in the dark, confined environment of a DISSUB. Additionally, both responders and casualties may be wearing protective overgarments with toxic gases or flooding in the associated spaces. Thus, there is a need for development and implementation of equipment to assist first responders in the rapid identification and triage of any survivors.

Three specific areas of technology were investigated in this initial assessment: biosensor monitoring, expedited location of casualties, and rapid life/death determination. Overall, 10 pieces of equipment were tested and only one was recommended for use in its current state. This was the Naval Firefighter Thermal Imager (NFTI) that is already in place onboard submarines. While several other technologies demonstrated great potential for future benefit, in their current state they were either prohibitively costly or their function was performed better using simpler and more reliable techniques such as confirming a palpable carotid pulse.

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BACKGROUND

Disabled submarine (DISSUB) crewmembers may face a number of potential threats to survival, including elevated carbon dioxide levels, hypoxic atmosphere, toxic gases, hyperbaric effects, and hypo- or hyperthermia.[1,2,3,4] This increases the possibility that some or all survivors may become unconscious or moribund prior to the arrival of first responders. Rescuers in such a scenario are tasked with identifying and differentiating unresponsive but salvageable survivors from the dead. This is a challenging task in the combat arena, but of considerable difficulty in the dark, confined, and often inaccessible DISSUB environment. DISSUB Medical Entry Team Responders presently have no prescribed system of locating and retrieving unresponsive survivors (personal communication, CDR Horn, Naval Submarine Medical Research Lab). Rescuers, who may be medically inexperienced, may be ill-equipped to accurately and expeditiously identify and diagnose the unresponsive patient. The Disabled Submarine Rescue Vehicle (DSRV), currently the U.S. Navy's primary submarine rescue asset, is not simply a transport vehicle, but also the first echelon of treatment analogous to the first ambulance arriving on scene. Navy DISSUB rescuers require equipment and procedures permitting a rapid survey of the DISSUB to locate unresponsive survivors requiring immediate attention in what could be a hazardous environment.

There is a host of innovative, sophisticated non-invasive detection equipment engineered to detect survivors in a variety of casualty scenarios. Some of this equipment is commercial off-the-shelf technology, but some equipment is developed exclusively by the military. For example, the Army's Combat Casualty Care Research Center has optimized numerous noninvasive, non-contact detection devices in the chemical and biological warfare theater.[5,6] Although many elements of any triage scenario can be found in a DISSUB, the elements of darkness, hypoxia, hypercarbia, and confinement are unique. This report describes trials to adapt and identify effective devices recommended for use by the first responder in a DISSUB scenario.

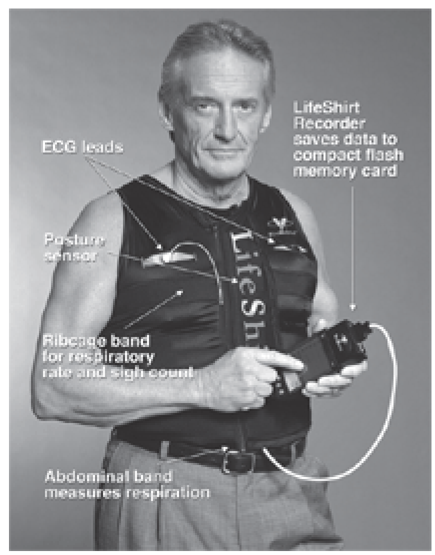
METHODS

Each instrument tested was analyzed in a matter particular to its function. The details of this analysis are contained under the individual descriptions in the results section below. All input received was from healthcare providers from different backgrounds and different stages of training that had some form of contact with a submarine environment. For each instrument, providers were given brief instruction on the proper use. They then attempted to utilize the devices in the prescribed manner. These tests were performed with both live personnel and plastic mannequins as the "test survivors." The environments the devices were tested in ranged from dark corridors and adjoining office rooms with obstacles obstructing the walkways to flood and damage control trainers that represented a close replica of engineering spaces aboard a ship.

RESULTS

Biomonitoring

<u>*Vivometrics Lifeshirt and Sarcos Company Life Belt.*</u> This equipment is a biosensor monitor for submariners capable of giving real-time, continuous medical data and possibly location in event of a DISSUB scenario. Both of these instruments are very similar, so they are reviewed together with differences addressed specifically. The shirt is embedded with multiple monitors to include an ECG, a skin surface thermometer, an accelerometer, and plethysmograph to monitor heart rate, respiration rate, temperature, and orientation (walking, supine). The life belt is a device that can monitor similar parameters, but is a band worn across the chest.



It is unreasonable to expect constant wear of this device in day to day operations, so it is assumed that the shirt or belt would be donned only in special circumstances: an impending DISSUB scenario, currently in a DISSUB scenario, monitoring individuals until they escape from the submarine or are rescued, or during fire fighting and diving operations. These biomonitors could function as research or environmental health tools as well since biologic data for individuals working in stressful conditions could be continuously observed.

Storage space required would be minimal and this equipment is lightweight (under 1kg). Both of these devices were reviewed in previous studies for reliability and validity. The results of those reviews indicated that the Lifeshirt was the better of the two in that regard, but that both provided reliable information.[7] Another study reviewed the acceptability of multiple biosensors for wear and found that belt-type monitors were more acceptable than the vest-type form for heating and comfort reasons.[8] However, this testing was performed on infantry soldiers and the primary complaint with the shirts was overheating. Although submariners are exposed to an entirely different environment than infantry, hyperthermia remains a threat for DISSUB survivors. The temperature of a DISSUB will be dependent upon ambient water temperature, residual heat from recently or currently running machinery, exothermic reactions from life support chemicals (e.g. oxygen candles or lithium hydroxide), number of survivors, and any flooding or fires present. Although the shirt could present a problem in elevated temperatures, in a cold or flooded compartment it may be able to provide extra warmth.

The shirts are currently designed with a recorder that fits into one of the pockets, however, wireless transfer of information is available. The lifebelts use wireless capability to transmit their data to a laptop utilizing proprietary software. This wireless capability could enable remote medical monitoring and determine the relative location of multiple individuals from a central wireless relay station. Furthermore, if the monitors were serialized and assigned to specific, matching individuals, information transmitted would not only include biologic data, but the identity of the individual wearing the monitor as well, provided there was no switching of the assigned instruments between personnel. This could assist in accurate accounting of all hands onboard a DISSUB. Such a system, when coupled with a device that could relay information to the surface, could give immediate information on number of survivors, their condition, and their locations on a DISSUB to the rescue team on the surface without any active communication or effort from the DISSUB below. This could be extremely conducive to a focused, planned, and efficient rescue effort. It would also enable advance planning of personnel/supplies required for rescue and real-time monitoring of survivors for medical planning as well. Once the first responders boarded the submarine, these devices could relay the location of most survivors easily in the dark, confined environment.

Wireless capability must be further explored on board submarines in general prior to considering this application. There are plans for newer submarines to have wireless networks onboard, so this equipment could probably be integrated into their existing systems making integration relatively simple and cheap. For older submarines, an assessment of cost and function for installment of wireless relay stations must be considered, as there are no plans to add them currently.

The battery life of these devices is approximately 72 hours, with the battery being the heaviest part of the gear. Ideally, the life of the battery would be extended to at least a full week, which is the target survivability for personnel in DISSUB scenarios.

There is no estimate of price yet assigned to these devices, but if one monitor were to be obtained for every crewmember onboard, the initial investment would be substantial. If the intent is to provide serialized monitors permitting for the identification of the wearer, the initial cost would rise even higher. Additionally, integration into the older class of submarines still serving in today’s Navy would require the addition of wireless capability throughout the submarine, which would be prohibitively costly if no plans were already in place for this upgrade.

Without wireless capability, which may be lost in any case of a DISSUB scenario, the benefits of these devices are seriously reduced. They would still monitor and record vital signs at the scene, but remote monitoring and assistance in location would be lost.

Advantages
1. Currently the most robust solutions to the continuous monitoring of survivors
2. May facilitate location, identity, and status via a central location on the submarine
3. Due to lightweight and compact design, easy to store and use onboard submarines
4. Life shirt is FDA approved and has passed validation and reliability testing in life signs monitoring

Disadvantages
1. Costs will be a significant factor, especially if addition of wireless capability factors into price and prohibitive when considering purchasing units for the entire submarine fleet
2. Needs further evaluation for ruggedness, particularly in prolonged immersion, vibration, and impact
3. User acceptance for long-term wear and donning in cases of emergency
4. Battery life of 72 hours falls significantly short of the 7-day goal of DISSUB survival equipment function.

Comments
1. Once these monitors are integrated with a wireless network and a communication device to surface, they would represent the best solution to obtaining remote real-time physiologic information about personnel on DISSUB that is currently available.
2. In the current form of the lightweight shirt or belt, it is conceivable that each submariner could wear assigned monitors in specific circumstances. Further exploration in extension of battery life and miniaturization of battery would make this an even more attractive solution
3. Based upon the potential of this equipment, further observation of this technology is recommended. However, the costs involved in outfitting an entire submarine crew, let alone the entire submarine fleet, would be prohibitively expensive at the present time.Once these monitors are integrated with a wireless network and a communication device to surface, they would represent the best solution to obtaining remote real-time physiologic information about personnel on DISSUB that is currently available.

Compartment Scanning

<u>*Radarvision By Time Domain Corporation.*</u> This is an ultra-wide band motion detector that was originally designed for through-wall scanning utilizing frequencies of 2.1-5.6 GHz. It was designed for use by law enforcement for scanning rooms for potential suspects or hostages prior to rapid entry. This technology was exhibited because the equipment is lightweight, rugged, and designed to be sensitive enough to detect the motion of breathing. It is able to penetrate most materials including brick, reinforced concrete, concrete block, sheetrock, wood composites, plaster, tile, and fiberglass. It is

highly desirable to possess technology that would enable scanning of multiple compartments, especially through bulkheads, for the presence of survivors when the compartment on the other side of the bulkhead is potentially compromised with water, fire, or toxic gases.

This technology proved to be of limited effectiveness because of the inability of microwaves to penetrate metal bulkheads. Additionally, a large amount of reflections from the walls created an excessive amount of noise making it difficult to distinguish a moving person from background reflections. There was an attempt to use this technology by "leaking" the signal through O-rings in a hatch without success.

In order to make this technology even feasible, there would have to be a coupling unit outside each bulkhead that would allow the device to send and receive signals on the other side. However, even with this modification, there would be the reflections from the walls making it difficult to determine the presence of survivors, let alone determine numbers of survivors.

During testing, 7 survivors were placed in various orientations, some concealed by equipment, in a completely dark environment. The Radarvision unit required extensive training and the time to initiate the search for survivors was long. Additionally, none of the 4 responders was able to locate all 7 survivors with the Radarvision due to reflection noise.

Even with training, this device does not perform optimally in a DISSUB environment. Furthermore, if this is the primary means of locating casualties, then errors in interpretation may cause a survivor to be missed. Thus, a physical search would always have to follow the use of this device to ensure that no survivors are left behind. Due to the interference and the risk of missing a survivor, this technology is not recommended for submarines.

Advantages
1. Able to detect a casualty through walls without exposing operator to risk

Disadvantages
1. Signal unable to penetrate space bulkheads of submarine
2. Signal reflections make detection/interpretation difficult
3. In order to be viable, coupling units would have to be installed in bulkheads
4. In the compartment being scanned, reflections may create false impression of motion

Comments
1. Technology impractical aboard submarines

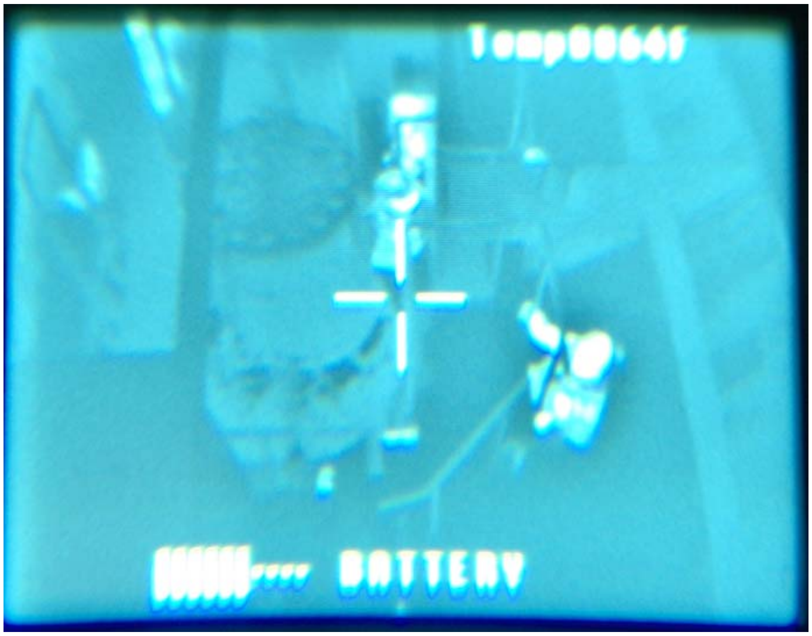
<u>*Naval Firefighter Thermal Imager (NFTI).*</u> This is a small, handheld device that displays an infrared image of the field of view of the camera lens. Regardless of room temperature, all objects emit some long wavelength infrared radiation. The infrared spectrum is invisible to the human eye but penetrates through smoke and can be detected even without visible light. Certain materials such as water or glass do not transmit infrared radiation.

The NFTI is designed as a thermal imaging, real-time camera, with a lens and infrared detector to collect infrared radiation. It then uses electronic circuitry to convert the signal

into a visible format for display. In the display, hot objects appear bright and cool objects appear darker. This allows the NFTI to not only detect survivors but also to detect fires or overheated equipment. The unit weighs less than 5 pounds and is less than 12 inches in the longest dimension. It uses normal or rechargeable batteries with a nominal life of 4.85 hours. It is waterproof, flame resistant, and capable of wireless transmission to a remote command center display.

Currently, the device is used by firefighters in the US Navy to assess spaces for presence of fires or heat sources near combustible materials, in addition to navigation and personnel search in dark or smoke-filled spaces. The operation is relatively simple and only minimal instruction (< 2 minutes) is required to accurately operate the NFTI. The NFTI electronics have been reported to heat up and cause a "white-out." However, this problem occurred only when the NFTI was exposed to extreme heat during the investigation of extremely hot fires.

During our testing, the NFTI was noted to perform exceptionally well for compartment scanning. It will not detect personnel behind walls or bulkheads but will provide a very quick and accurate assessment of any survivors in the line of sight. One period of testing involved placing 7 subjects in various orientations, some partially concealed by equipment, in complete darkness. When 4 responders were compared in a head-to-head trial, all 4 identified the locations of 7 survivors within seconds, almost instantly. This exercise was attempted with a flashlight and was much slower, but all survivors were located eventually as well. Although some survivors were partially obscured, the smallest protrusion of skin surface into line of sight of the NFTI allowed for instant location, making it much better than a flashlight in all conditions.



As mentioned previously, these devices are already in use aboard submarines. For a rescue effort, additional NFTI units should be provided to the first responders. These units are expensive, costing in excess of $15,000, but represent an operational, fully tested, and very capable piece of gear for rapid location of survivors. Responders need very few units to conduct searches and if this unit should fail, responders always would be able to fall back on flashlights for search efforts.

Advantages
1. Lightweight, easily portable, and easy to use
2. Able to function well in dark and smoke-filled areas
3. Accurately, easily, and quickly locates survivors inside a closed compartment
4. Long battery life
5. Already in operational use in the fleet

Disadvantages
1. Expensive instrument
2. Requires search of each individual space

Comments
1. A robust solution for scanning for survivors
2. With wireless integration, possible to provide video feed to a central station for further supervision in searches or navigation

<u>Lifefinder by Gamefinder, Inc.</u> This is a handheld, portable instrument that operates on "temperature edge line" changes for detection. Essentially, there are two temperature-sensing elements at the end of the probe with a gap in the middle. The unit is used to sweep across a room and whenever the two elements read different temperatures, the LED on the device will illuminate. Detection of an edge of an object with a temperature difference

from the surroundings is indicated on the LED. The LED is scaled from 1 to 10 depending on the gradient and the user settings. While scanning from side to side, it should clearly detect a heat source against a cool background. Electronics and software are integrated in this device to improve sensitivity and specificity for human and animal detection.

The Lifefinder weighs 260 grams and is powered by a disposable 9-volt battery that will run for 15 to 20 hours. The unit is compact, with the longest dimension being approximately 15cm. Its operational range is claimed by the company to be several hundred yards, functioning from below 0 to about 100 degrees Celsius, with a sensitivity of 0.1 degrees Celsius.

During our evaluation, this instrument was used to attempt to locate survivors. It was too sensitive; readily picking up lights, computer equipment, as well as body heat. Several different rates of side-to-side scanning were performed without a great increase in specificity. The instructions mention that considerable practice may be needed before accurate use of the Lifefinder is achieved. Even after adjusting the instrument to its most specific setting, it was difficult to determine if the detection signal was a person or an electrical or ambient heat source. In order to accurately identify a source of heat, one must also use triangulation or scan from multiple angles.

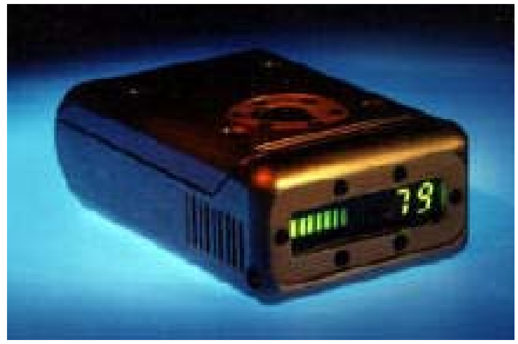
For compartment scanning onboard a DISSUB, specificity is required. There could be multiple sources of heat, such as oxygen candles, in addition to the survivors. Thus, this instrument does not provide a reasonable solution.

Advantages
1. Lightweight, portable
2. Easy and quick to activate with few settings
3. Long battery life

Disadvantages
1. Much too sensitive and not specific
2. Requires significant training/practice to use effectively

Comments
1. This device does not offer a reasonable solution for fast, accurate compartment scanning
2. Would not recommend further evaluation or investigation for this technology

Life/Death Determination



<u>Lifedetector fom Southwest Research Institute.</u> This instrument is a seismic heart rate detector that was designed to detect a heartbeat through multiple layers of clothing and over garments. While initially funded by the Army, its development has been curtailed but a prototype was evaluated in our exercise.

The device is designed to detect small vibrations in the chest wall from a beating heart. It is placed on the subject's chest or back and the user releases the unit. If a responder holds the unit, vibrations from his body may trigger a false positive reading. After time, an LED on the device displays signal(vibration) intensity and heart rate if a pulse is found. The device specifications indicate that an evaluation requires at least 6 seconds. It uses a lithium battery that provides enough power for 800 evaluations. Environmental vibrations may interfere with the reading, especially cyclical vibration from 40-200Hz. It can withstand 5 minutes of full immersion but is not rated as "waterproof".[9]

Our exercise noted that this device was accurate, but that the delay in reading seemed excessively long (>20 seconds in some cases). Another problem noted was the casualty must be lying on a flat surface since the user must completely release the device. Such a device cannot be used if a survivor is in an orientation other than supine/prone or during transport. The reliability of this device in the presence of environmental vibration was not tested.

In mass casualty situations, multiple devices such as this could be carried by responders and placed on multiple unresponsive casualties. Within seconds, triage decisions could be made for a large number of casualties based upon the displayed results. However, a palpable carotid pulse provides a much faster response and is a basic skill requiring only a minimum of training.

Advantages
1. Simple to use and interpret
2. Requires little training
3. Accurate and reliable in ideal environments
4. Small, light, and with good battery life

Disadvantages
1. Needs supine/prone motionless casualty to accurately evaluate
2. Environmental vibration is known to cause errant results
3. Not waterproof
4. Excessive time required to evaluate a casualty

Comments
1. Improve resistance to water, evaluate for impact testing
2. Maintain function with vertical orientations or with movement- consider handle able to filter out responder interference
3. Need to decrease the time required to complete evaluation of a casualty
4. Given that this is a simple technology to use and interpret, improvements may be put to effective use. Future observation of this technology may be warranted

Micro-Life Detection Radar by Advantaca. This is a personal digital assistant (PDA) based instrument that relies on microwave pulse Doppler radar to detect the presence of pulse or breathing. It is designed to detect chest motions associated with breathing or chest vibrations associated with heartbeats. It consists of two parts: a micropower radar/data acquisition element and a PDA. The unit is designed as a case into which most PDAs will fit and integrate into the unit. The unit emits a signal in the microwave range frequency (450-1150 MHz) and the reflections are received as a Doppler change in amplitude. The unit utilizes a band-pass filter to focus on frequencies relative to biologic activity. Specifically, it monitors the 0.03-5Hz range which corresponds to approximately 2 breaths per minute on the low end and a heartbeat of 300 beats per minute on the high end. This enables the unit to filter out surrounding vibrations/motions that may give a false positive result. It is able to detect the motions through clothing and has a range of 2 feet around the emitting unit. Specifications state that batteries provide up to 3 hours of function with the PDA and size is 4 inches in the largest dimension with a weight of 7oz.

Calibration is required prior to use to prevent interference from environmental vibrations. Power-up and warm-up will take approximately 3 minutes prior to calibration. Calibration consists of placing the unit on an inanimate object while all responders withdraw from the 2-foot range of the unit. Once the calibration is initiated, it will take 34 seconds before the unit is ready, indicated by a red light and "no life" signal. In order to evaluate a casualty, the unit must be placed on the individual and the responder withdraws from the effective range and waits for the reading. If the casualty is breathing or has a pulse, the unit should indicate this within 6 seconds with a green light and "life detected" signal. It will take 34 seconds to determine the absence of life, which will be indicated by the red light and "no life" signal. If there is excessive interference that prevents an accurate reading, the red light is displayed alone (without a "no life" indication). Thus, there may be false positive readings as a result of noise, but there should never be a false negative due to noise interference.[10]

During the initial exercise, the unit received was completely non-functional. Repair attempts were made, guided by technician via telephone without any success. Based upon company-provided information alone, our evaluators felt the examination time to determine life was acceptable at 6 seconds, but 34 seconds to determine absence of life was excessive. Determinations of less than 10 seconds are desirable. This is also another device in which a responder must place the unit on the casualty and step away for the reading to take place. There is neither validity data provided for the instrument by the vendors or independent studies, nor is there any information concerning survivability in water or impact.

On a follow-up exercise, the unit functioned accurately during checks just prior to the exercise, but started to give only negative readings despite repeated attempts at calibration and use involving multiple medical providers. This unit proved ineffective and unreliable on two different occasions when tested. While this technology may hold potential in the future, this particular instrument simply failed to function in a reliable and consistent manner.

Advantages
1. Simple to use and interpret
2. Minimal training required
3. Small, portable

Disadvantages
1. Must be released and left alone to process data
2. No validity data
3. No ruggedness testing known
4. Requires too much time to determine death
5. Poor instrument function during our exercises

Comments
1. Technology may provide for future improvements in the device, however this particular instrument does not warrant further evaluation
2. Consider directional beam and/or handle that filters out interference from responder so this device can be handheld
3. Reduce amount of time required to determine the absence of life

Biolog 3000. This instrument provides portable, real-time ECG and heart rate readings. It is small, easily handheld, and has a battery life of approximately 12 hours. It comes with cables that enable a 6- or 12-lead connection, but the unit is constructed with built-in contact electrodes on the back that enable a reading within seconds when pressed against the bare chest wall without cables, patches, or gels. The resulting ECG can be stored in memory for later transfer or printing. It presently has no backlight in the unit for low-light conditions.

The ECG portion can accurately assess heart rates from 20 to 250 beats per minute and can display a single rhythm strip for 200 seconds or a 12 lead for up to 10 seconds. The electrodes on the back of the unit function by simply pressing the unit against the patient's bare chest, thus providing contact to all four terminals simultaneously.
This device provided accurate results quickly and required little training or effort to use.

Without a backlight, the display was difficult to read, but otherwise this device functioned very well. Testers remarked that it was sometimes difficult to get contact on all 4 terminals on the back of the unit due to chest morphology (i.e. large pectoral muscles). The addition of a backlight is a necessity for interpretation of the results in a dark environment. The most significant drawback of this device is the requirement for access to bare skin to obtain a reading.

Overall, this represented one of the best units to assess the presence of life. Simple, handheld, and easy to use; it offered good data in any orientation and could be used during transport as well. Testing with significant environmental vibration was not performed. Excessive motion of the device would produce some deviation in the readout, but as long as the unit was held firmly against the chest wall, motion noise was hardly apparent. In addition to confirming electrical activity in the heart, it displays the rhythm, which may alert responders to other abnormalities. While it can be used in a variety of situations, the ability to obtain an ECG in a DISSUB scenario is questionable since advanced cardiac treatments and resuscitation may not be immediately available.

If simply used to determine life or death, fairly extensive training to the users in interpreting ECG will be needed to differentiate between accurate and errant results. Additionally, casualties need to be unclothed to bare chest, which requires more time than taking a carotid pulse. This unit would not be as fast and requires much more first responder training. With addition of a backlight and perhaps wireless transmission to a trained interpreter, this device could be useful in certain circumstances. However, use of this device is difficult to recommend for first responders in a DISSUB scenario.

Advantages
1. Quickly supplies accurate, useful data
2. Minimal training to operate device, simple operation
3. Especially small, light, and portable
4. Long battery life

Disadvantages
1. Accurate interpretation of ECG requires considerable training
2. Needs direct access to bare skin to function
3. Requires backlighting to effectively read display
4. Difficult to ensure contact across all 4 electrodes on certain chest types such as those with large pectoral muscles

Comments

1. With slight modifications, adding a backlight and perhaps extending the contact electrodes, this device could be an excellent solution to evaluation of casualties in a variety of situations.
2. Consider wireless transmission for sending data to experienced interpreter for assistance.
3. Technology merits further observation, but ultimate applicability in the DISSUB scenario is questionable

Phonocardiography. This is simply an electronic stethoscope linked to a PDA that translates auscultation sounds into a visual display. Thus, the device displays heart sounds as a phonocardiogram or visual representation of the heart sounds. Additionally, the device can store data for later analysis/review. The requirements for the equipment are only that an electronic stethoscope must be used that has an appropriate digital output jack and a PDA capable of running the appropriate proprietary software. Thus, this is a small, lightweight, and easily portable unit whose battery life and ruggedness is limited only by the equipment chosen for use. The overall cost for gear used in this trial was approximately $700 for the PDA and electronic stethoscope.

During our exercises, this instrument produced excellent results in several different scenarios. The stethoscope in use, the Androscope I-stethos™, was electronic and possessed noise-canceling capability. On one trial, considerable interference was noted on the phonocardiogram, with background noise of multiple conversations within the room. This background produced too much noise to clearly listen with the stethoscope and produced a poor phonocardiogram image on the PDA. In a quiet environment, the phonocardiogram signal produced was clear and easy to interpret.

Listening to the heartbeat as well as viewing the display permits useful correlation of the visual and audio information provided. Interpreting the visual data on the PDA in the absence of hearing the heartbeat requires some training. If a responder is using this to assess signs of life or death, they will only need to identify a repeating tracing of a heartbeat.

This instrument would require further testing using a variety of stethoscopes to find the combination best at noise-cancellation and to provide the optimal phonocardiogram. This device has potential, since the phonocardiogram can detect very faint heart sounds. This gear can be used through thin layers of clothing, although optimal performance occurs without any clothing obstructing contact.

This technology is fairly mature and could be invaluable in specific circumstances. Potential applications include a helicopter medical evacuation, when background noise makes it impossible for a responder to hear heart sounds, even with a noise-canceling stethoscope due to conduction of the sound through the body. If a stethoscope was effective at canceling noise, the visual display of the phonocardiogram could still permit inspection of a patient for breath or heart sounds while in flight. However, on a DISSUB, there is no expectation of loud noises that would require a visual representation of what is heard through a stethoscope. Furthermore, given the time required to expose the stethoscope on the bare chest wall and the amount of training and expense required, it is difficult to recommend this to first responder teams for a DISSUB scenario versus taking a carotid pulse.

Advantages

1. Small, light, easy to use
2. Use of software on variety of equipment provides flexibility
3. Visual display simplifies detection of heartbeat for inexperienced users

Disadvantages

1. Requires further testing with variety of stethoscopes and PDAs to determine optimum configuration
2. Background noise can interfere with phonocardiogram, noise-reduction is a requirement

Comments

1. With further testing and improvement, the phonocardiogram could be used to differentiate between living and deceased casualties in certain circumstances although this does not apply specifically to DISSUB scenarios since background noise is not an issue
2. Potential exists for operational use if noise cancellation is improved- on a battlefield or during helicopter transport where noise prevents use, the phonocardiogram may still be able to give vital information

Portable Ultrasound. Ultrasound could be used by first responders to detect the presence of a heartbeat, as well as fluid in the lungs and blood in the abdomen or cranium. Furthermore, it can used to guide procedures, such as chest tube placement. The first ultrasound devices were too large to be portable, but miniaturization has produced an instrument that is easily transportable.

The unit tested was the SonoSite Elite that consists of a small handheld probe and a small case with a monitor and is slightly larger than the average laptop. It has the potential for use in a variety of environments by any individual. It is quite simple to activate the ultrasound and use the probe, but acquiring a readable image and interpreting the results requires extensive training. If the intent is only to detect a heartbeat, the training could be relatively brief. Otherwise many hours of training would be required for proficiency in the other uses.

The unit tested was the SonoSite Elite that consists of a small handheld probe and a small case with a monitor, overall slightly larger than the average laptop. It has the potential for use in a variety of environments by any individual. It is quite simple to activate the ultrasound and use the probe, but interpreting the results requires extensive training. It is conceivable that some training could be provided if the intent is only to identify a heartbeat. Otherwise several hours of training would be required for proficiency in the other uses.

This technology is very well developed and available for commercial use. However, it is also very expensive with each unit currently costing in excess of $20,000. The cost of outfitting possible responders would be considerable, as would training required to use this equipment. Another factor to consider is the actual interventions that would be available or necessary in a DISSUB. If bone fractures or blood in the abdomen were detected, the decision to promptly evacuate the casualty from the DISSUB is unchanged. Additionally, any interventions performed while on board the submarine would further delay definitive care. If used simply for detection of heartbeat, it is a very expensive option, particularly when compared to a carotid pulse palpation. This technology also requires application to bare skin, increasing the time required to use of this device.

Advantages
1. Small, light, easy to use
2. Reliable, proven technology- available commercially
3. Has great potential in diagnosing a variety of medical abnormalities

Disadvantages
1. Expensive
2. Requires extensive training for interpretation
3. Requires bare skin for examination

Comments
1. Excellent, mature technology for evaluation of injuries
2. Use and application in DISSUB scenario is limited

Table 1- Summary of Findings

Device Tested	Current Practice	Relative Cost	Time Response	Reliability	Future Utility
Vivometrics LifeShirt	None	High	Continuous	Excellent	Poor- Expensive to outfit entire fleet
Sarcos Life Belt	None	High	Continuous	Excellent	Poor- Expensive to outfit entire fleet
TimeDomain Radarvision	Flashlight	Moderate	Unusable	Unusable	Poor- Unusable onboard submarines
Naval Firefighter Thermal Imager	Flashlight	Moderate	Rapid	Excellent	Excellent- already in use in fleet
GameFinder LifeFinder	Flashlight	Low	Slow	Poor	Poor- Unreliable
SWRI Life Detector	Palpable Pulse	Low	Fair	Good	Fair- Needs to be faster
Advantaca Micro-Life Detector	Palpable Pulse	Moderate	Slow	Poor	Poor- Unreliable
Biolog 3000	Palpable Pulse	Low	Good	Interpretation	Fair- EKG of questionable value on DISSUB
Phonocardiogram	Palpable Pulse	Low	Fair	Interpretation	Fair- environmental sound likely a non-issue
Portable Ultrasound	Palpable Pulse	Moderate	Fair	Interpretation	Fair- extensive training required for use

CONCLUSIONS

Most of the technologies evaluated have potential for future application in a variety of settings as noted above, but very few provided an attractive solution to triage onboard a DISSUB. For the purposes of locating casualties, the NFTI was unexcelled and is already deployed on board ships and submarines. First responders in a DISSUB event can use this device to expedite location of survivors. For life signs determination, no instrument tested offered an acceptable alternative to the comparative standard of the palpable carotid pulse. Carotid pulse palpation is cheap, simple, reliable, and fast when compared to the technologies evaluated. While biomonitoring does have potential for use onboard submarines, it is difficult at this point to recommend supplying the fleet with biomonitors for every crewmember onboard. With continued miniaturization, reduced costs, and further development of communications on a DISSUB, the biomonitors may become feasible equipment in the future or in different environments and circumstances.

Even though most of these technologies do not present a solution to triage on a DISSUB scenario, they do have potential for use in other operational environments. For example, the phonocardiogram might be used in a noisy environment (medical evacuation helicopter) to monitor patients. Thus, the phonocardiogram may possess great utility in other environments even though it does not in the DISSUB scenario, but these evaluations are beyond the scope of this project.

While this report reviewed technology and instruments currently available, emerging technologies, as well as previous technologies that have been improved by continued miniaturization and decreases in cost, should be monitored regularly. There is still a need for improvements for quick and accurate triage in the DISSUB rescue scenario.

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